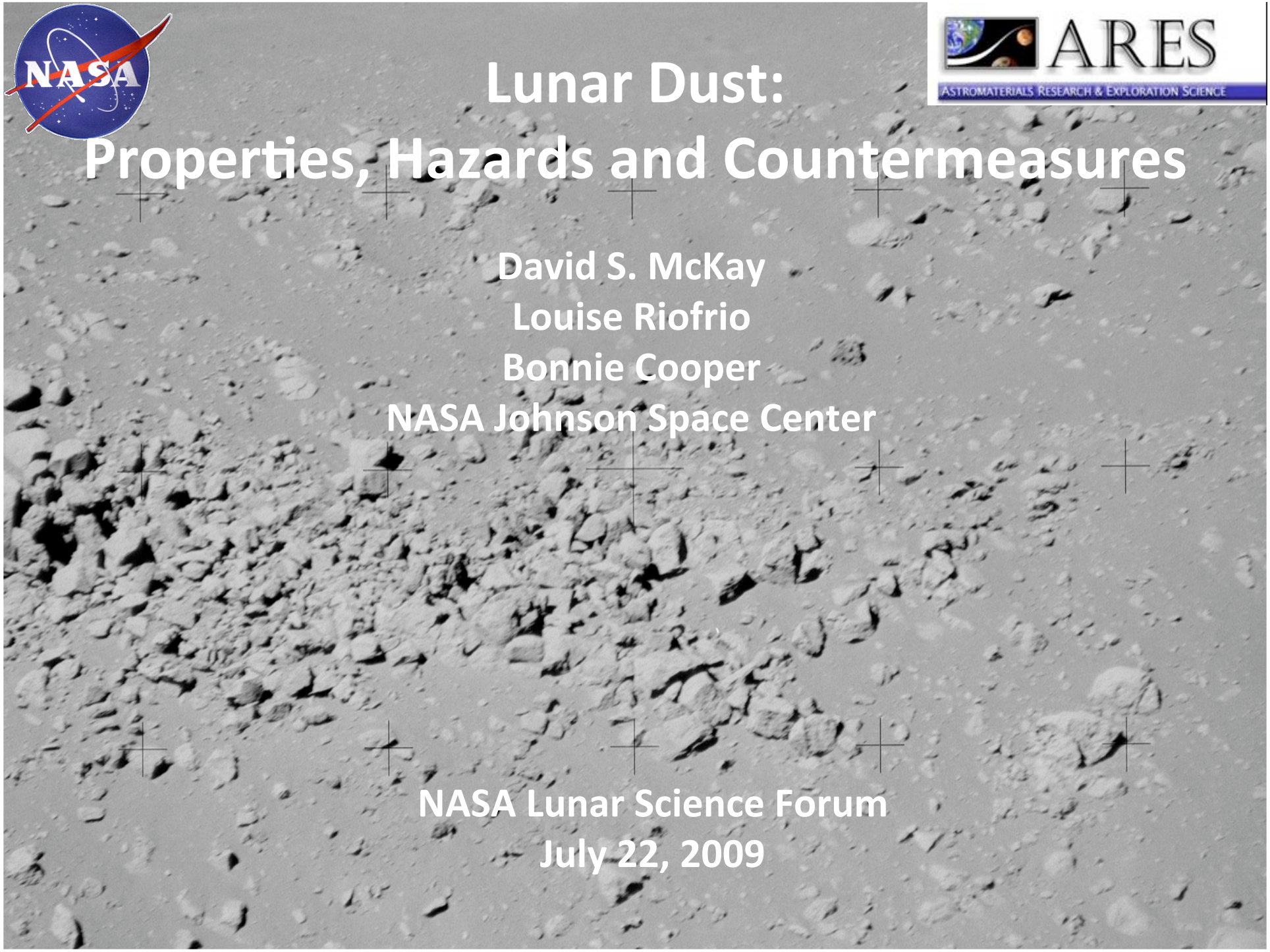
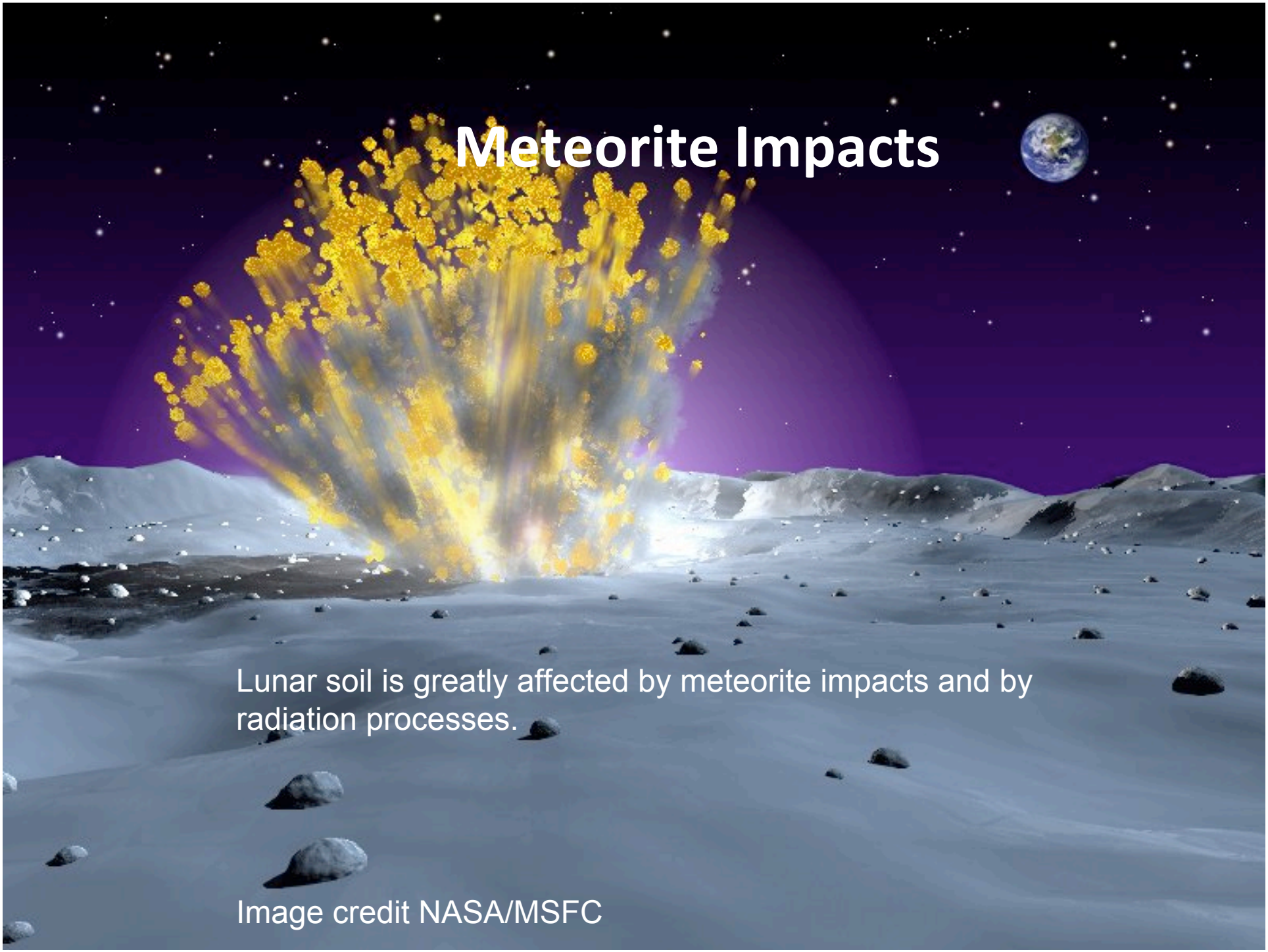


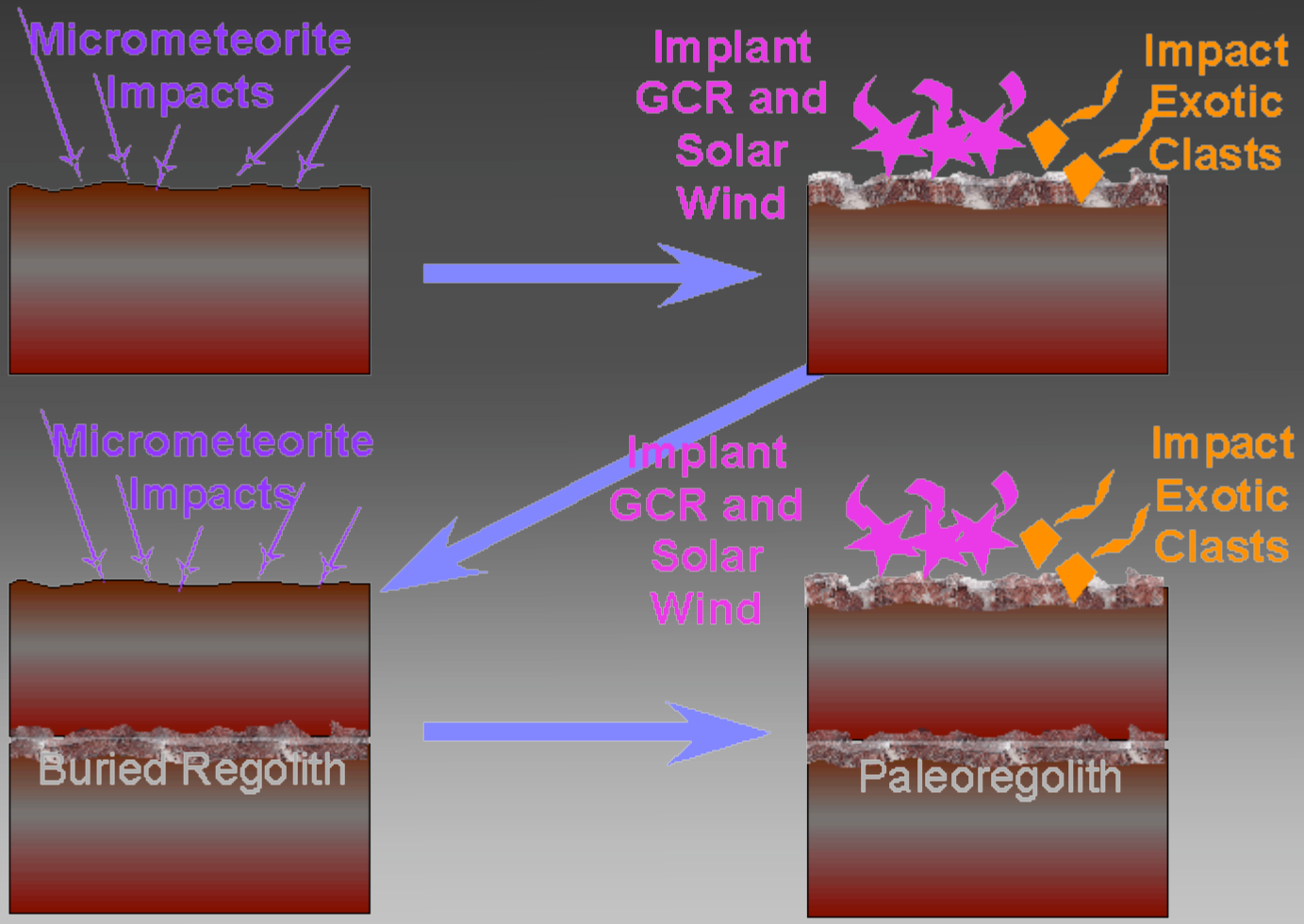
Lunar Dust: Properties, Hazards and Countermeasures

David S. McKay
Louise Riofrio
Bonnie Cooper
NASA Johnson Space Center

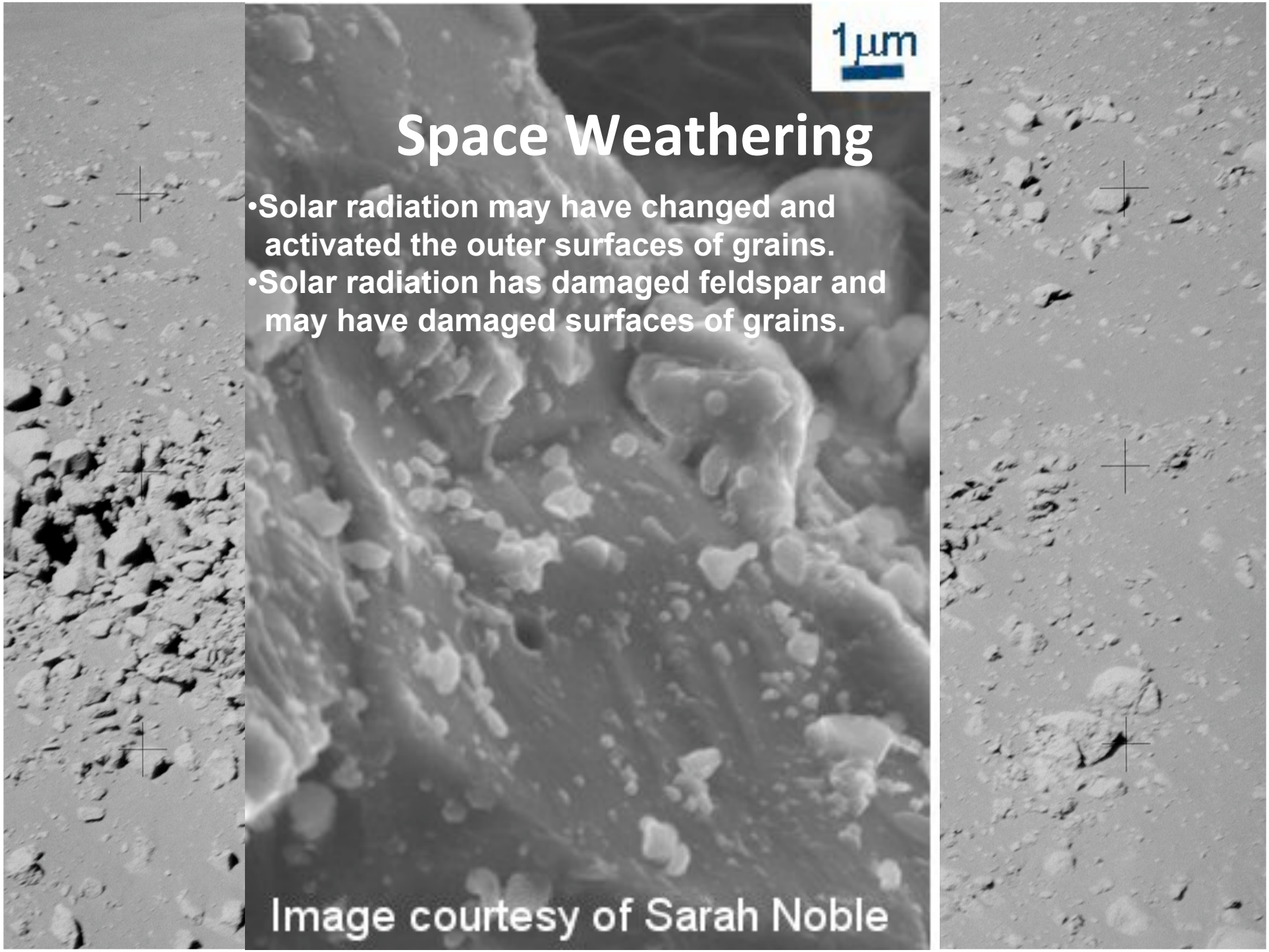
NASA Lunar Science Forum
July 22, 2009


Meteorite Impacts
Lunar soil is greatly affected by meteorite impacts and by radiation processes.
Image credit NASA/MSFC

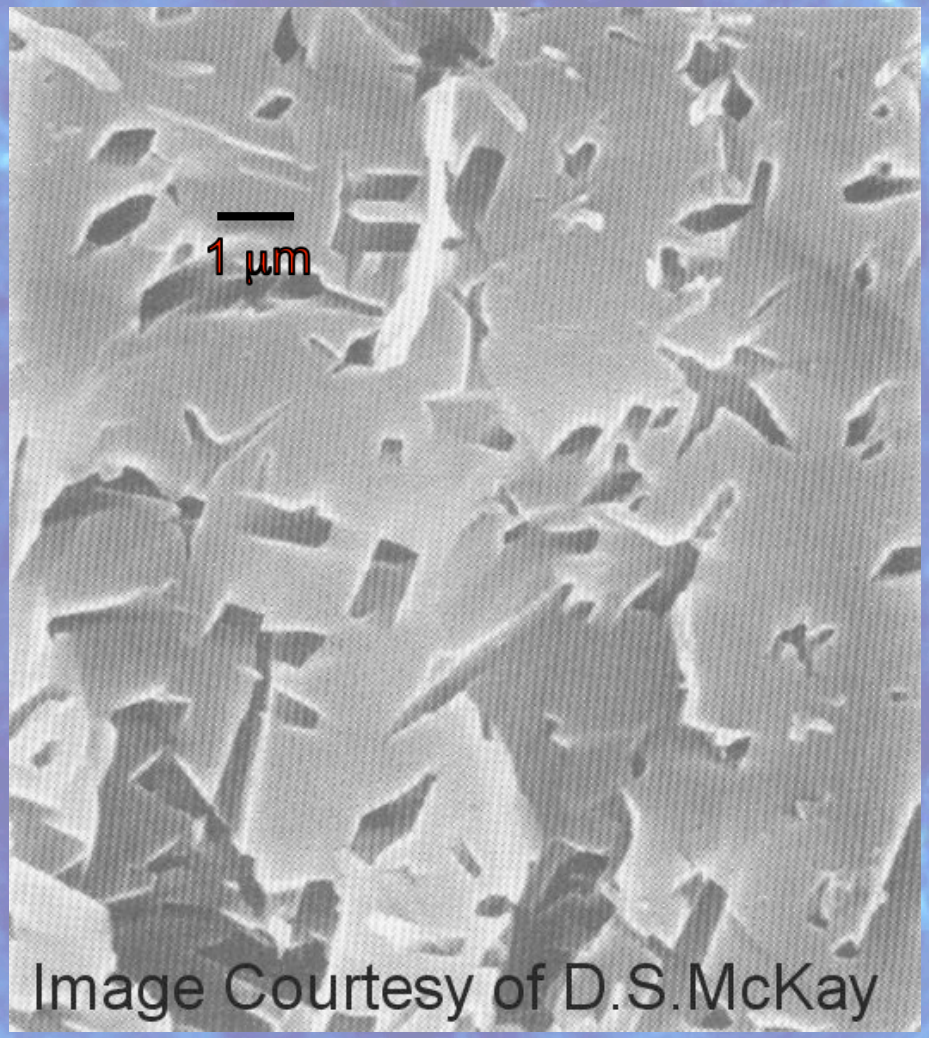
Regolith Development



Modified from Crawford et al., 2007


1µm
Space Weathering
•Solar radiation may have changed and activated the outer surfaces of grains.
•Solar radiation has damaged feldspar and may have damaged surfaces of grains.
Image courtesy of Sarah Noble

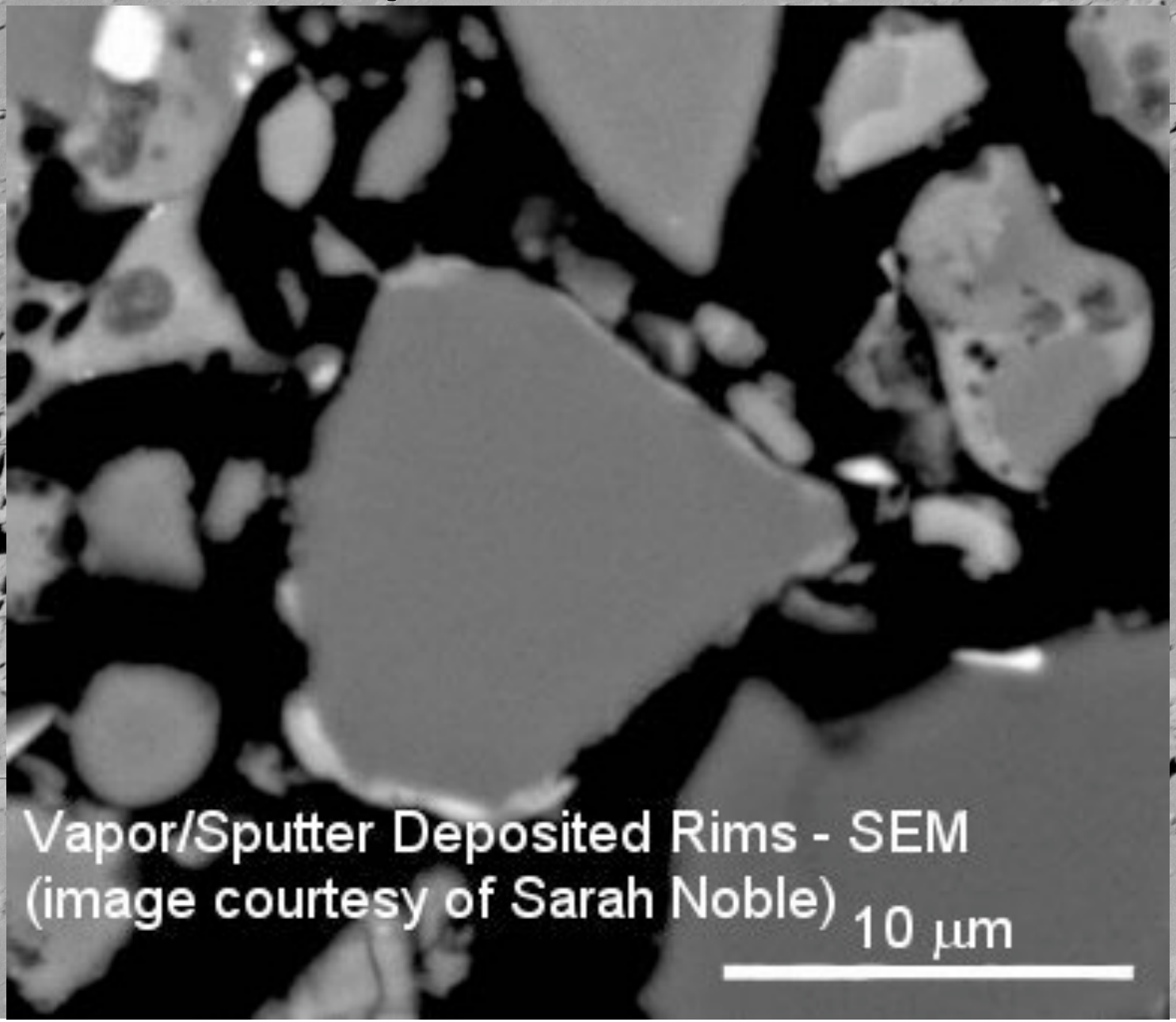
Solar radiation may have activated the outer surfaces of grains.



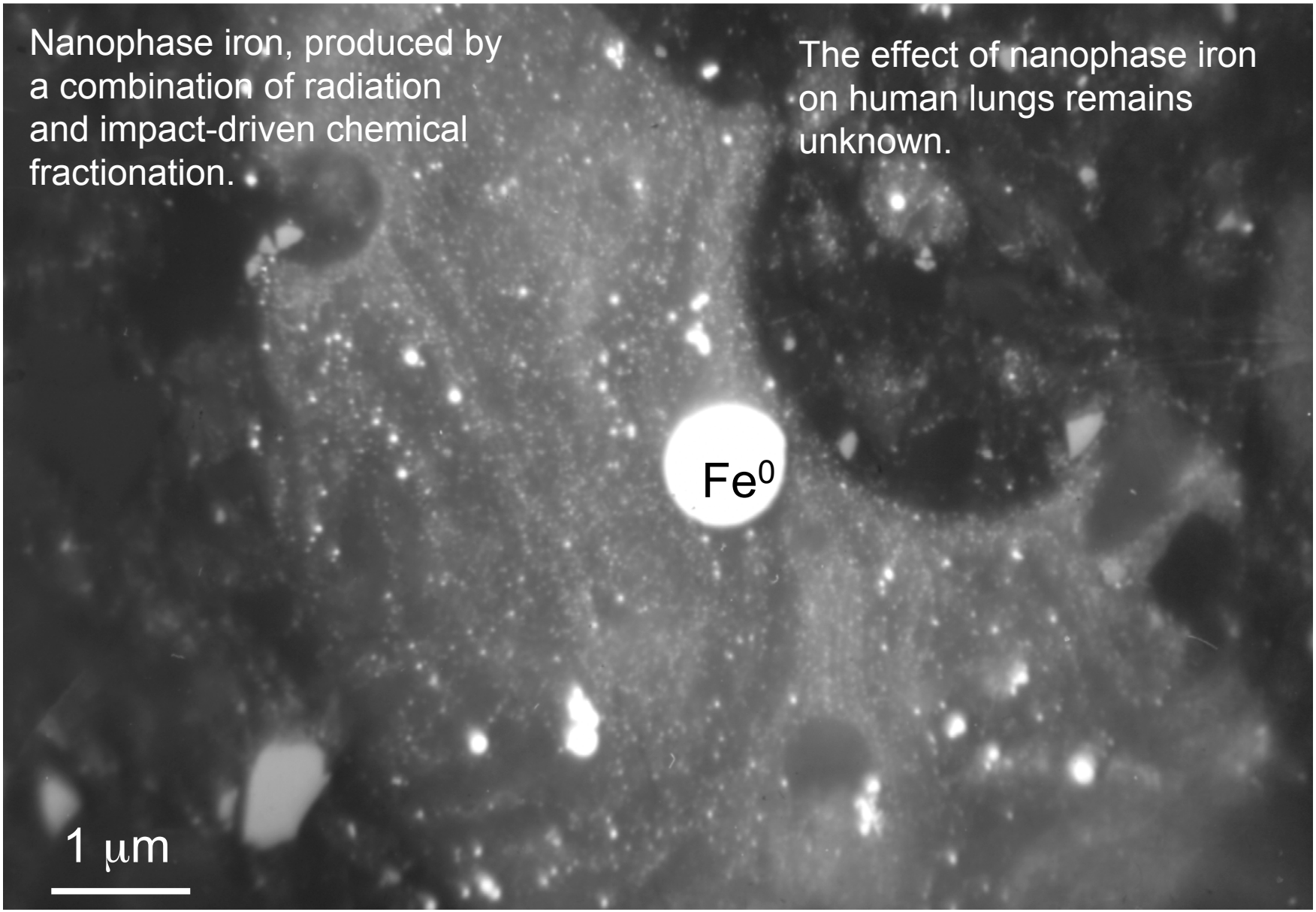
Etched particle tracks in lunar plagioclase feldspar

Solar radiation has damaged lunar feldspars; it may have interacted with ALL lunar grains.

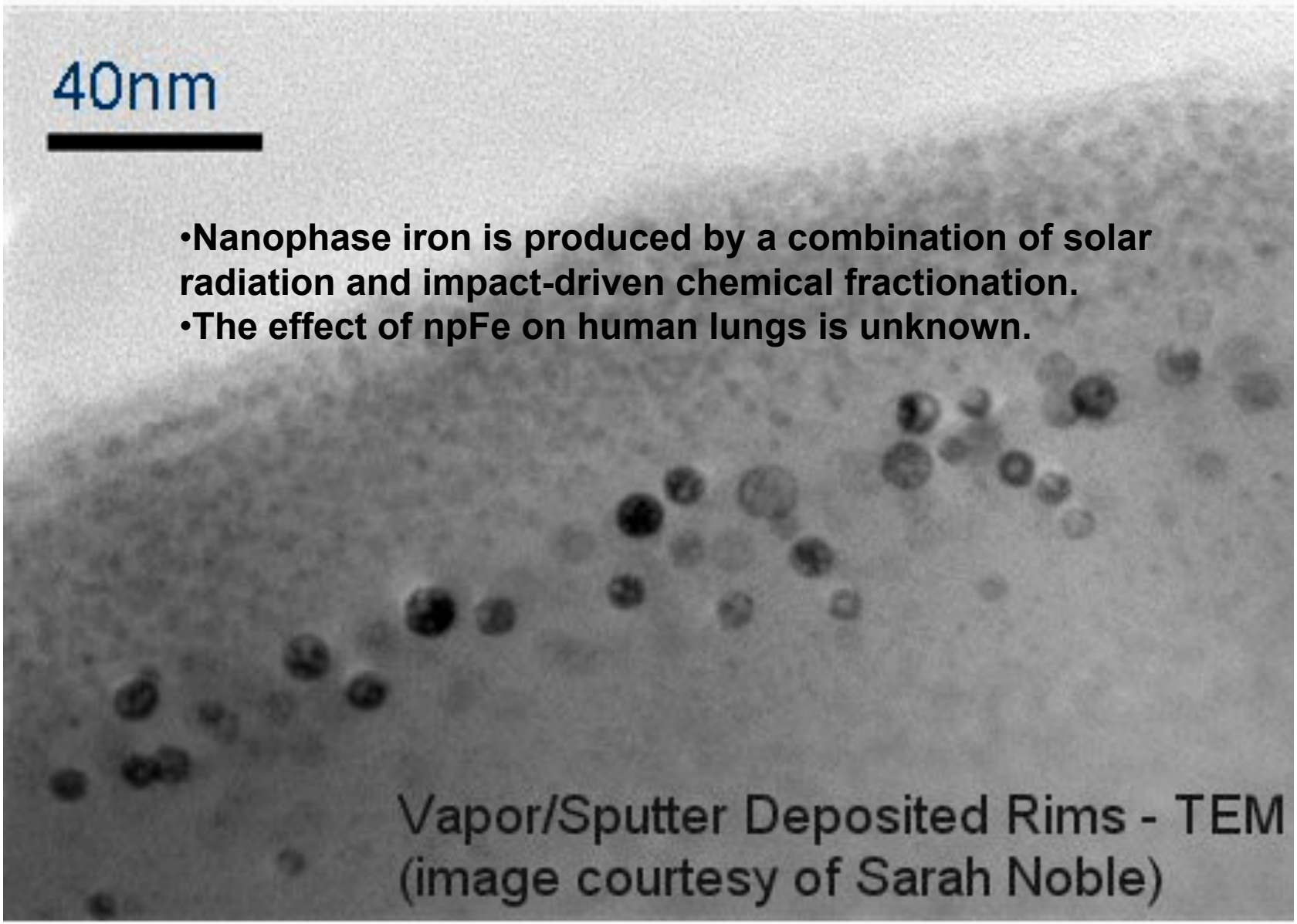
Sputter Erosion



Solar Wind

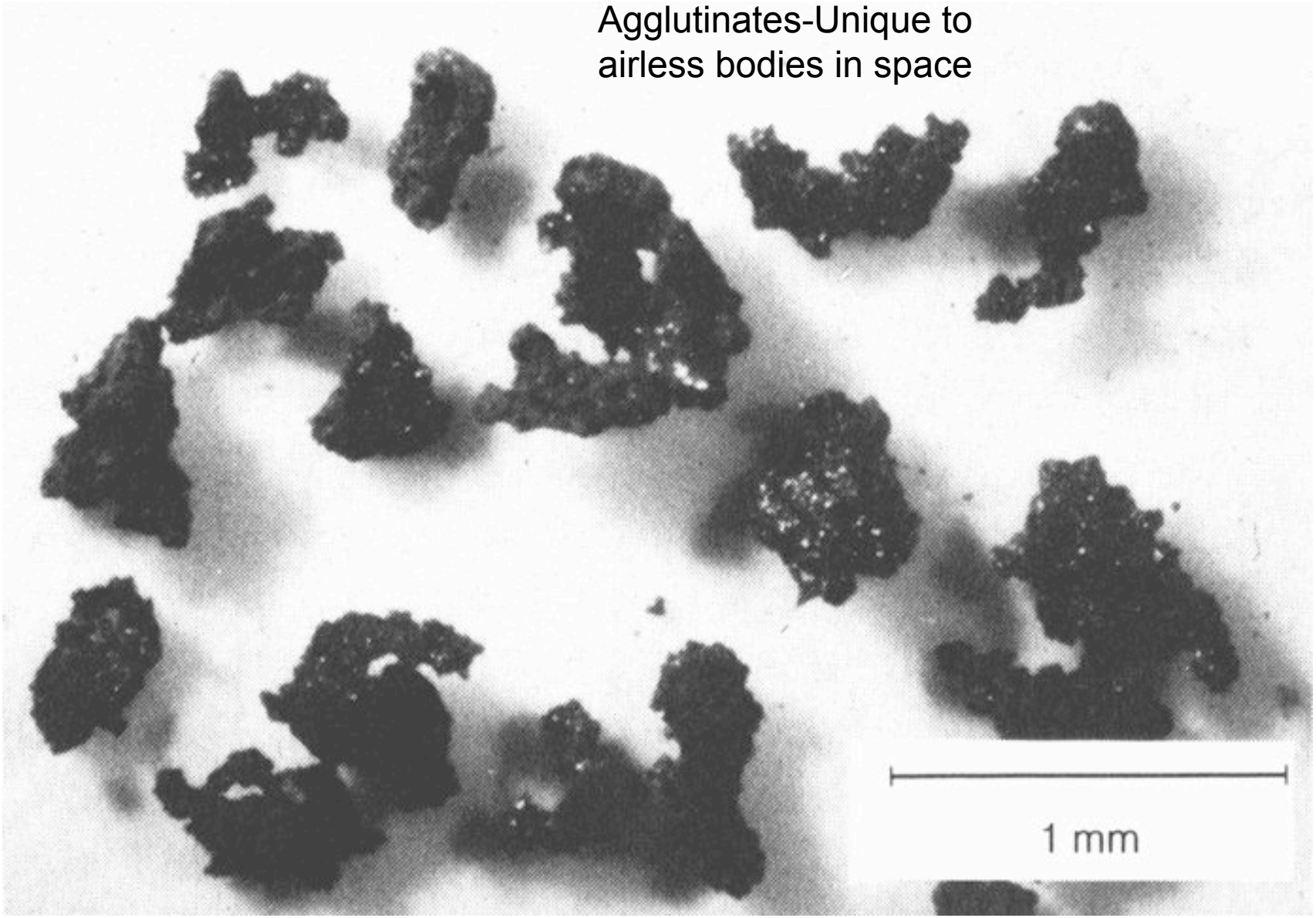

Nanophase iron, produced by a combination of radiation and impact-driven chemical fractionation.
The effect of nanophase iron on human lungs remains unknown.
Fe^0
1 μm

Nanophase Iron



Complex Shapes/Surfaces

Agglutinates-Unique to airless bodies in space



Why is lunar soil potentially dangerous to humans?

•Industrial dust on earth such as asbestos and freshly fractured quartz are known to cause severe lung damage and death when inhaled for any significant time

•Destruction to lungs arises from a combination of shape parameters and activated grain surfaces with free radicals, surface defects, and other properties

•Lunar soil may have some of these properties as well as others not encountered previously for any significant way by humans

•Exposure times by Apollo astronauts were a few days; exposure times by industrial workers such as sand blasters are typically months to years, although major illness can develop after only a month or so exposure.

•We need to establish the maximum permission limit for lunar crews for lunar dust as a function of exposure time and dust concentration in breathing air

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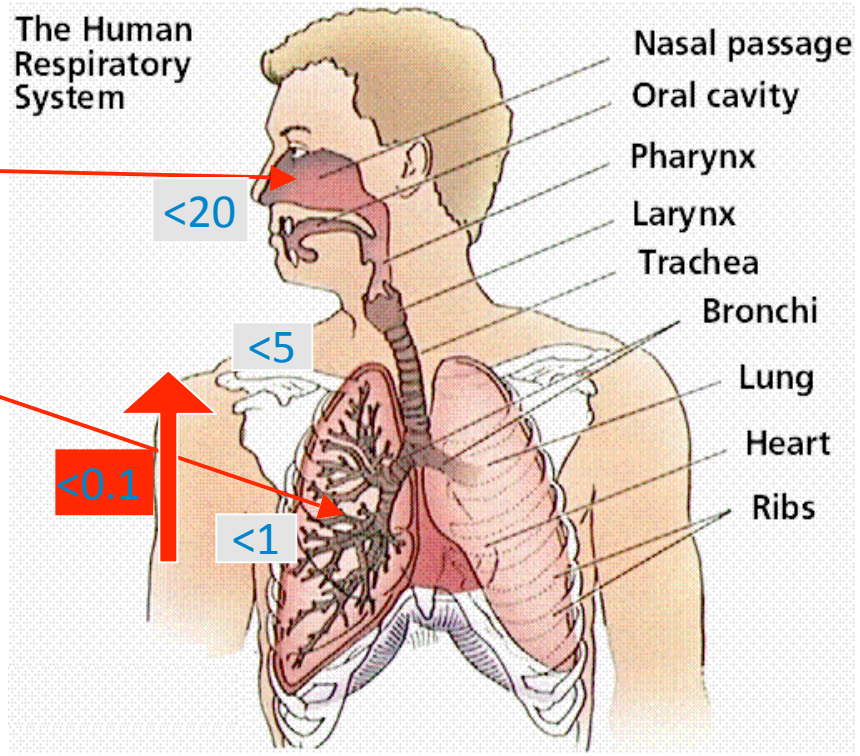
How does Crew become exposed to lunar soil and dust?

- Tracking it in on suits, boots helmets, gloves (Apollo)
- Can be controlled by leaving suits outside and using suit-airlock
- But;
  - Suits must eventually be brought in for maintenance
  - Other “outdoor” equipment need maintenance and cleaning
  - Spills may occur from inadvertent procedures or emergencies
  - Close examination of lunar rocks and soils in habitat or rover may be necessary

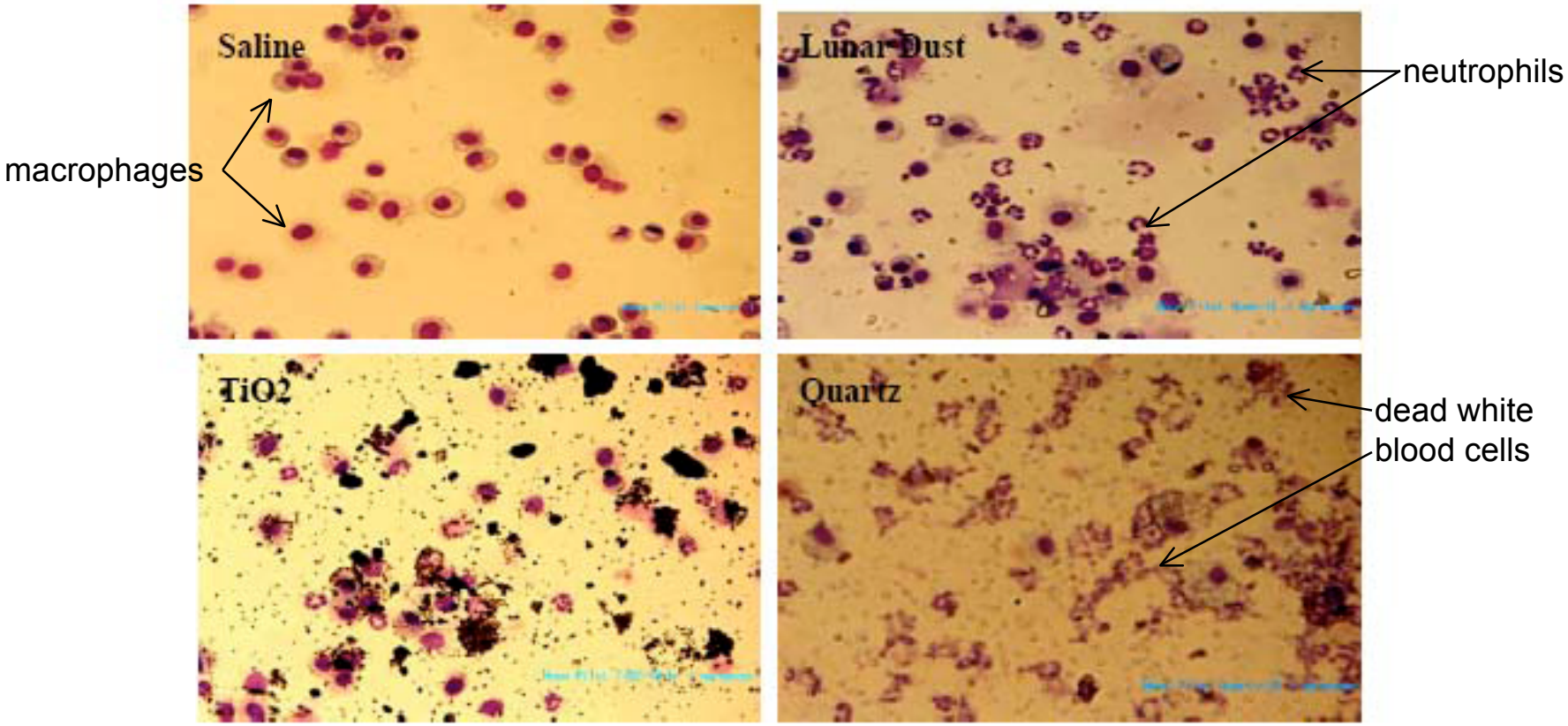
Known Toxic Effects of Dusts

- Dermal irritation & penetration
- Eye irritation & corrosion
  - Chemical
  - Mechanical
- Respiratory injury
  - Upper air ways
  - Lower airways
    - Edema
    - Inflammation
    - Fibrosis
    - Cancer?



Courtesy: J.T. James, NASA (2005)

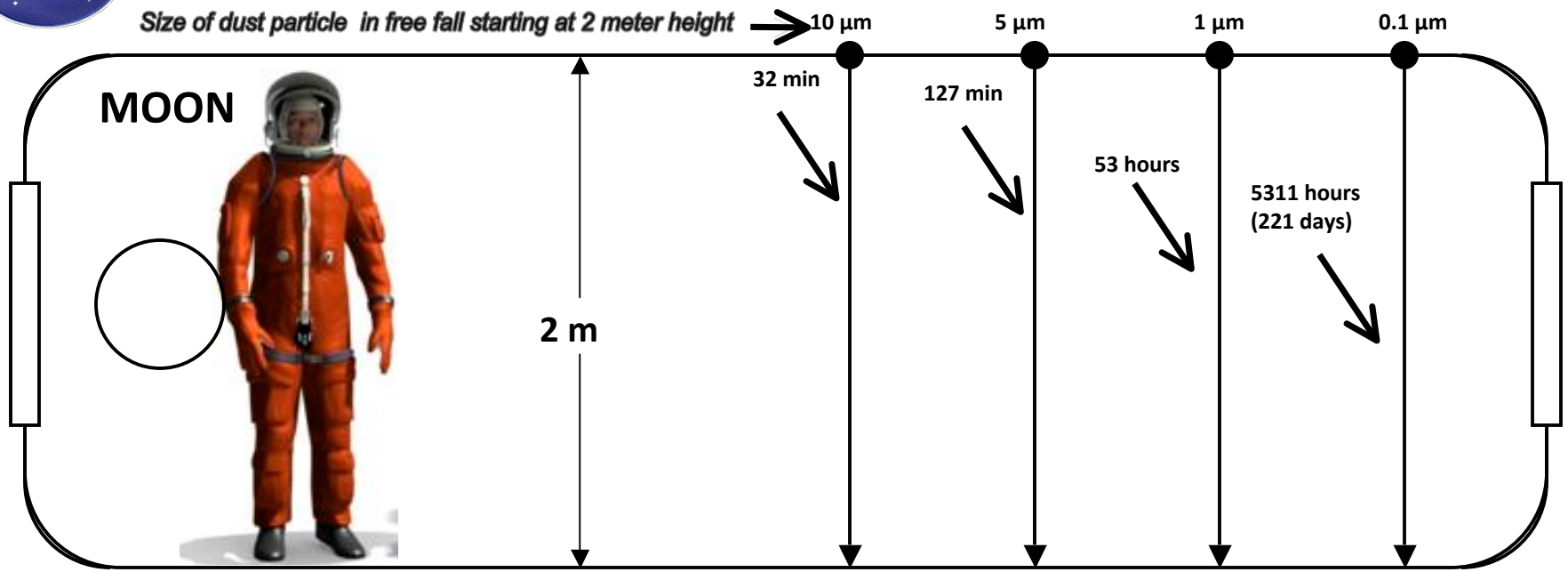
Lung Effects



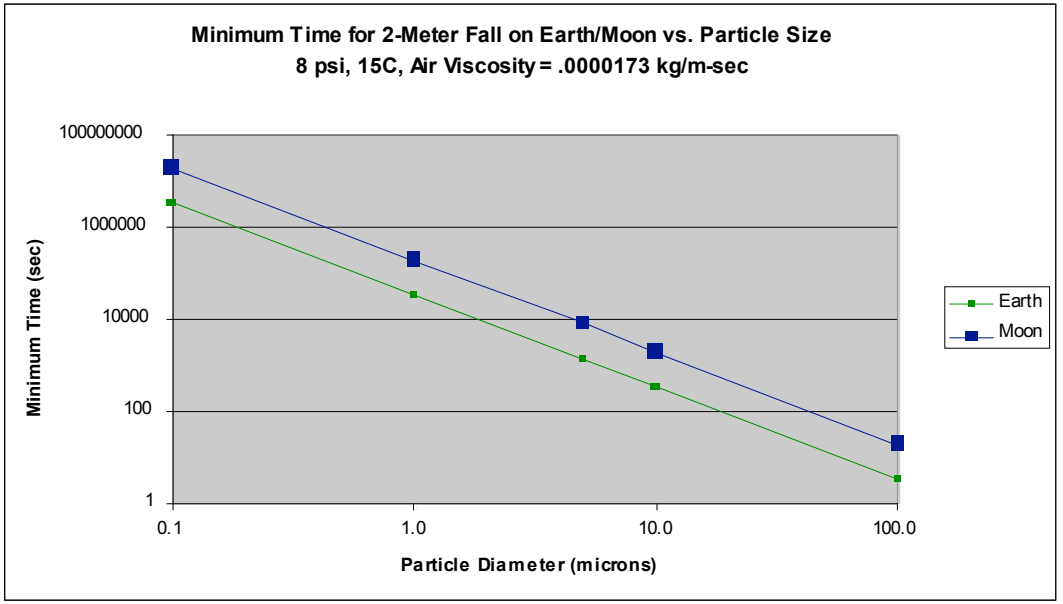
Influx of white blood cells (macrophages and neutrophils) into the lungs of mice after various materials were placed in the lungs via the throat.

Courtesy of Dr. Chiu-Wing Lam,
NASA JSC/Lunar Airborne Dust Toxicity Assessment Group (LADTAG)

Dust Fall in Habitat



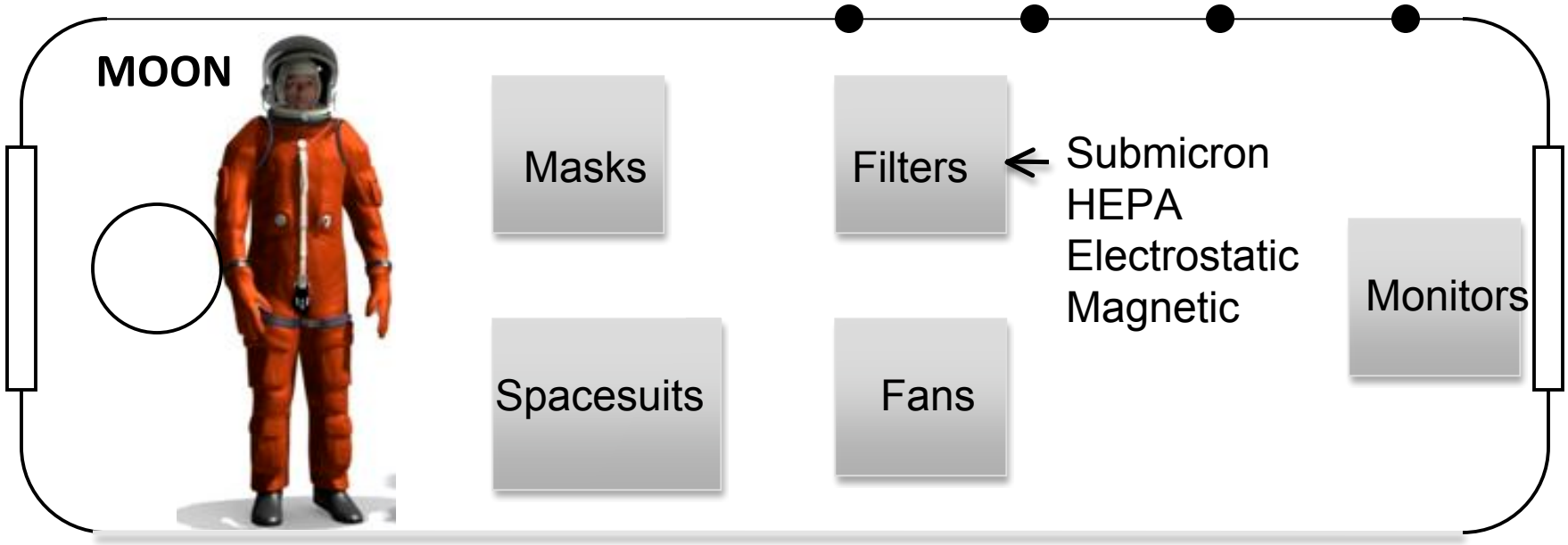
How long does it take to clear the air after bringing in lunar soil?



Assumes no air currents or disturbance

Shows that all grains in the respirable range(<2µm) take days to fall to deck!

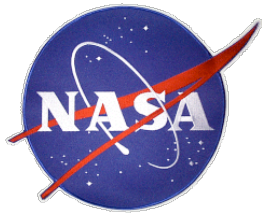
Countermeasures to Protect Crew



- ***Without engineering solutions, virtually 100% of lunar soil finer than ~2 μm will end up in the lungs of the crew***

- Must have filters, fans, and other controls to protect crew

- The question is how big must this system be and how much power will it require; the countermeasure infrastructure is heavily dependent on the exposure limits



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How do we separate fine-grained dust for study?

Sieving: Our team has sieved (mostly in the 1970's) and has published sieve data on almost all the Apollo returned soils and most cores including Russian samples. We have published more lunar soil size data than any other group in the world. We used precision electroformed sieves with square holes and a tedious procedure which included washing with liquid Freon, extensive microscope verification of each size fraction, and careful tracking of masses and recovery. A typical sample took a week or more to properly sieve and quantify.

We are now using laser systems (Microtrac Blueray and Nanotrac instruments) to compare to the sieve data and to extend the size data into the sub micrometer range. A typical analysis takes less than 1 hour.

We are now able to perform multiple analyses on each sample and resolve splitting and sampling issues,

We can now produce and quantitatively analyze size splits below the normal sieving size range using impactors, cyclones, and submicron filters.

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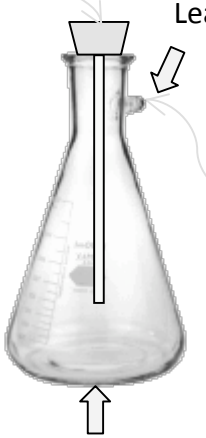
Pump

Drying Column

Fluidized Bed

Smaller Particles Leave Here



Settling Flask #1: Large Particles Collect Here

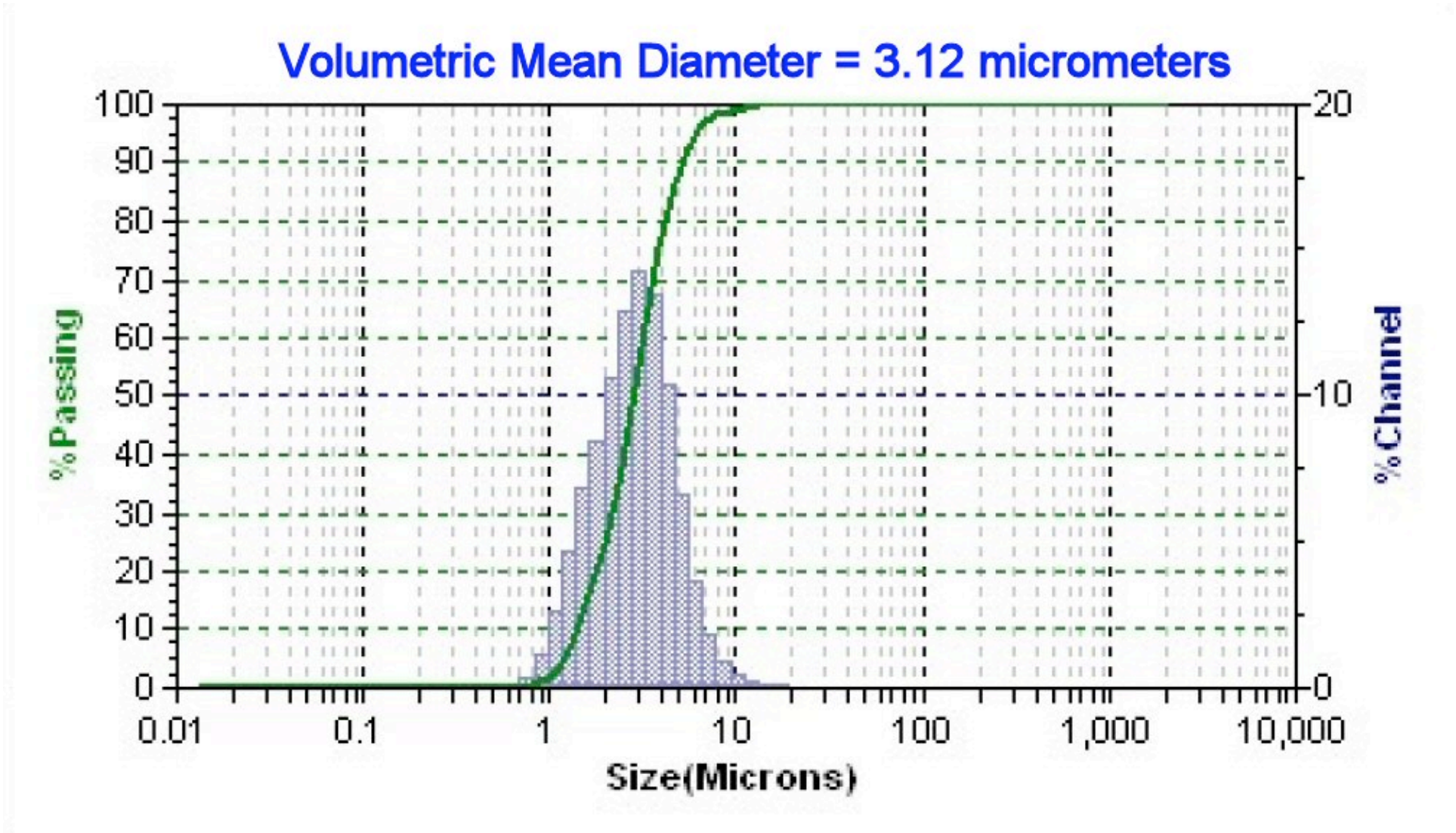
Smaller Particles Leave Here

Cyclone: Intermediate Particles (~10 μm) Collect here.

Settling Flask #2: Respirable Dust Is Collected Here

2.5 μm ashless Filter

0.05 μm PVDF Filter


Volumetric Mean Diameter = 3.12 micrometers
% Passing
% Channel
100
90
80
70
60
50
40
30
20
10
0
20
10
0
0.01
0.1
1
10
100
1,000
10,000
Size(Microns)

Conclusions:

- Lunar dust may be dangerous to crew health
- Closest industrial analog may be freshly ground quartz which is known to be quite dangerous
- LADTAG in 2006 set a preliminary dust exposure limit of 0.05 mg/m^3.

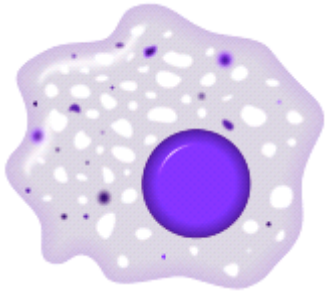
Conclusions:

The Lunar Airborne Dust Toxicity Analysis Group (LADTAG) will provide maximum Safe exposure limits for humans.

"The results of these studies are essential in setting the permissible exposure limits for lunar dust. Agency exposure limits ensure human health, in support of NASA's plans to return to the Moon.
These limits will be a main driver for the design of ports or airlocks for EVA, and will determine the requirements for filtering and monitoring the atmosphere in all habitable vehicles and modules. Excessively conservative limits will have significant cost impacts in both design and operations over the lifetime of the program."

Doug Cooke
Associate Administrator for
Exploration Systems
Mission Directorate
June 29, 2009

White Blood Cells And Neutrophils

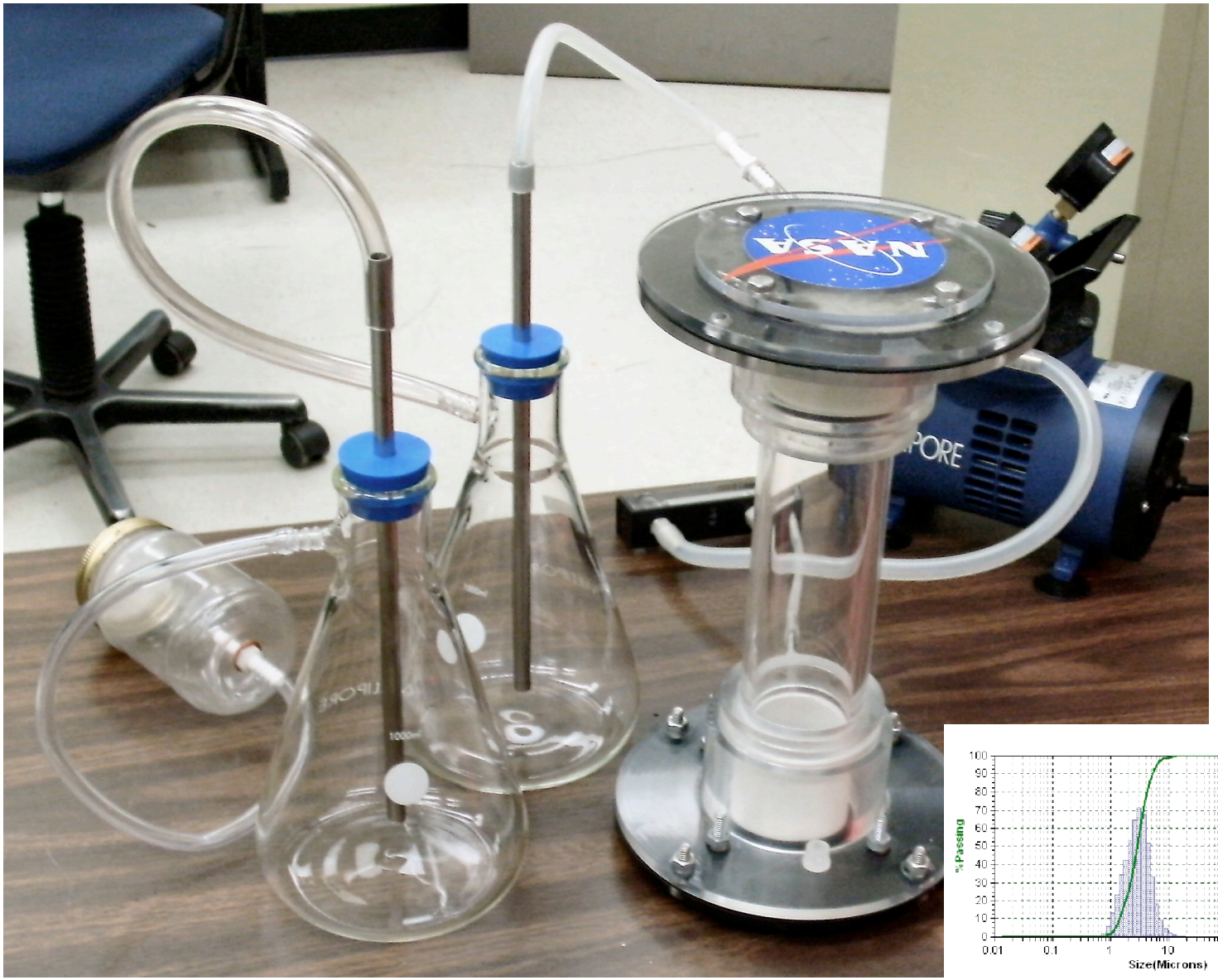


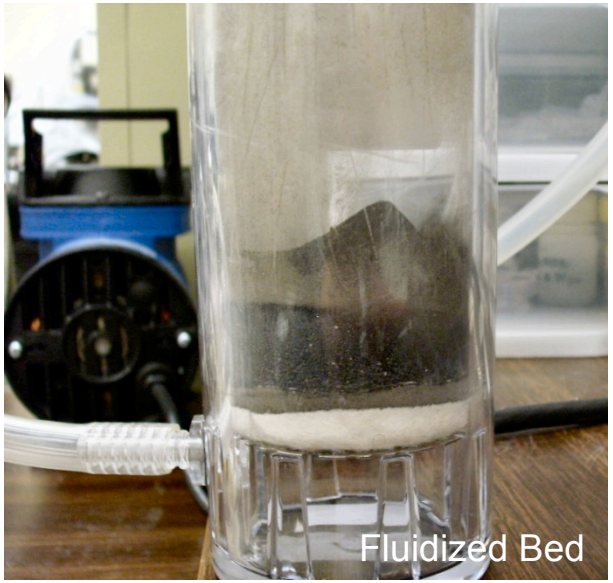
The pan-fried egg-shaped objects are white blood cells called macrophages (“big eater” cells). They are local soldiers in the lung that eat up bacteria; they also gobble up some dust particles.
If the dusts are toxic, they may die.
After encountering invaders (such as bacteria or toxic dusts), macrophages will also send out signals to the blood to recruit more solders (White Blood Cells).

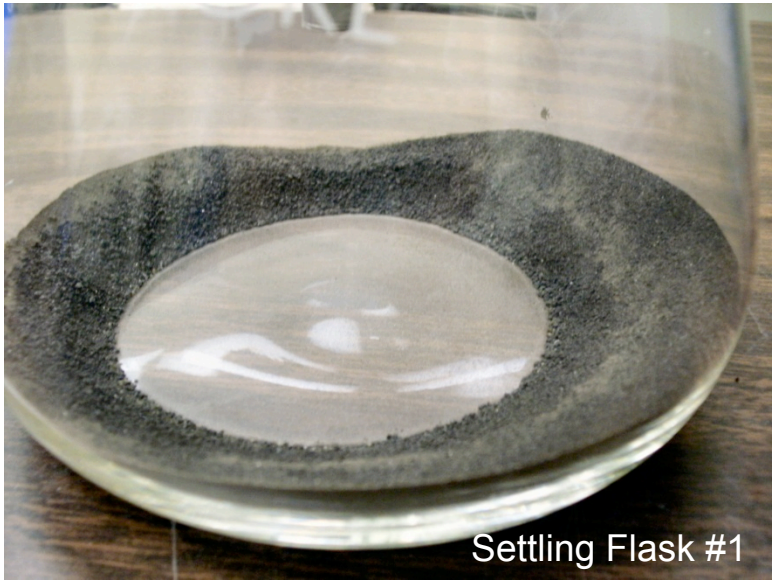
The neutrophils, the cells most likely responding to inflammation, will enter the lungs from the blood. The nucleus of a neutrophils appears like a broken/segmented shrimp.

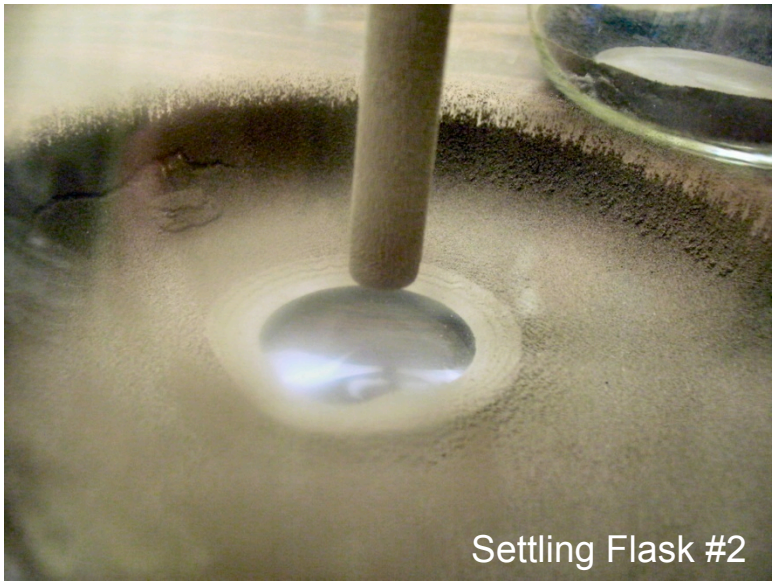
In the following pictures, the macrophages and neutrophils are stained red.

Dust Separation System




Fluidized Bed


Settling Flask #1


Settling Flask #2


Filter Paper (product material)